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A TECHNIQUE UTILIZING FREE-FLYING RADIO-CONTROLLED MODELS
TO STUDY THE INCIPIENT- AND DEVELOPED-SPIN
CHARACTERISTICS OF AIRPLANES

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A TECHNIQUE UTILIZING FREE-FLYING RADIO-CONTROLLED MODELS TO STUDY THE INCIPIENT- AND DEVELOPED-SPIN CHARACTERISTICS OF AIRPLANES

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SUMMARY

A technique, using free-flying radio-controlled models, has been developed to study the incipient- and developed-spin characteristics of airplanes. This technique consists of launching an unpowered model into gliding flight from a helicopter, controlling the model from the ground, and recovering the model by use of a parachute at the end of the flight. The report describes the technique and some preliminary results obtained on a model representing a contemporary fighter which was used in the development of the technique.

In general, the results obtained during the investigation indicated that the technique was feasible for studying the incipient and developed-spin characteristics of airplanes. The model spin and recovery characteristics obtained by use of this technique were in general agreement with spin-tunnel and full-scale results. It was found that the present radio-control equipment which provided flicker aileron and rudder control and trimmable horizontal tail, although limited with regard to maneuvering the model precisely, was fairly adequate for the development of the technique. However, in order to realize the full potential of this technique, it is considered extremely desirable to use proportional-control equipment when adequate equipment becomes available so that rapid and accurate positioning of the control surfaces will be possible.

INTRODUCTION

Because of current design trends of military airplanes, ensuring satisfactory recovery from the developed spin may be difficult without compromising the airplane too much for its intended use. Accordingly, emphasis is being put on termination of the spin while it is still in its incipient phase. Because of the high inertia loadings of current fighter airplanes, the tendency to enter a developed spin generally is delayed somewhat; thus, the pilot has more of an opportunity to move his control to avoid the spin. Consequently, information is very desirable on incipient spins (the transient motion obtained between the stall and the fully developed spin) including the control manipulations required to recover from the incipient spin in order to avoid the developed spin. It is believed that controls which may be ineffective in terminating a fully developed spin because of attitudes, rotation, and gyroscopic effects, may be effective in terminating an incipient spin. A small catapult facility exists at Langley for studying spin entries, but the lack of space severely limits this facility. (See ref. 1.)

In the past, the developed-spin characteristics of a given airplane design and optimum control technique necessary for recovery from developed spins could generally be determined quickly and efficiently in the Langley 20-foot free-spinning tunnel with dynamically scaled models. However, spin-tunnel experience has indicated that the long fuselage forebody of some current designs can have a significant influence on the spin and recovery characteristics. Furthermore, force-test data have shown that in some instances there can be a large scale effect on this particular portion of the airplane which may appreciably affect the spin-tunnel results obtained at low Reynolds numbers. Thus the model data from the spin tunnel might in some cases give either optimistic or pessimistic results, these results depending greatly upon the cross-sectional shape of the fuselage forebody. (See ref. 2.)

Another question that has given concern recently is the influence, for some designs, of the model launching technique used in the spin tunnel. The launching technique in the spin tunnel normally consists of launching the model by hand in a very flat attitude with forced rotation into a vertically rising airstream. Even though the model may spin flat in the tunnel when this technique was used, it is possible that the corresponding airplane may never reach this flat attitude because of a different spin-entry technique for the airplane. Therefore, as pointed out in reference 3, a question may arise in some instances as regards the interpretation of the model data obtained from a very flat spin in reference to the corresponding full-scale airplane.

In order to meet the need for a spin-research technique where the incipient spin may be studied and where the Reynolds number would be at a value to permit suitable comparison of model and full-scale data, a technique for using free-flying radio-controlled models has been developed. In addition, this technique may be used to simulate the spin-entry technique for airplanes. This technique consists of launching an unpowered model into gliding flight from a helicopter, controlling the model from the ground, and retrieving the model by means of a recovery parachute when the flight is completed. This report describes the technique and presents some preliminary results obtained on a model representative of a contemporary fighter.

SYMBOLS

b	wing span, ft
S	wing area, sq ft
$\bar{c}$	mean aerodynamic chord, ft
c	local chord, ft
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of perpendicular distance between center of gravity and thrust line to mean aerodynamic chord (positive when center of gravity is below thrust line)
m	mass of airplane, slugs
I_X,I_Y,I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-ft^2
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\frac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter
X,Y,Z	coordinate axes
ρ	air density, slugs/cu ft
μ	relative density of airplane, $m/\rho Sb$
α	angle of attack at nose boom, deg
β	angle of sideslip at nose boom, deg
Ω	full-scale angular velocity about spin axis, rps
δ_r	rudder deflection with respect to fin, positive with trailing edge to left, deg

δ_{a_r} right aileron deflection with respect to chord line of wing, positive with trailing edge down, deg

δ_t horizontal-tail deflection with respect to fuselage reference line, positive with trailing edge down, deg

t simulated full-scale time, sec

MODEL AND INSTALLED EQUIPMENT

Model

A three-view drawing of an approximate 1/9-scale model constructed in the Langley dynamic model shop is presented in figure 1 and a photograph of the model is shown in figure 2. As previously mentioned, the model is considered to be representative of current fighter-type airplanes. The unpowered model was provided with a metal can at the end of the fuselage to hold an emergency recovery parachute and a hatch in the fuselage just in front of the vertical tail was used to cover the main recovery parachute. The model was constructed primarily of laminated fiberglass cloth and plastic. The wings and tail surfaces had solid balsa cores whereas the fuselage was a 1/4-inch-thick hollow shell.

Radio Equipment

Simultaneous operation of the ailerons, rudder, and horizontal tail was achieved through the use of two radio receivers. One was a 5-channel receiver and the other a 3-channel receiver. These were audio-modulated receivers operating on radio frequencies of 73 and $27\frac{1}{4}$ megacycles, respectively. Two of the channels from the 5-channel receiver were used to control the ailerons, two other channels were used to control the rudder, and the fifth channel was used to release the main parachute either at the command of the pilot or automatically in a fail-safe manner when either the receiver or its transmitter failed to function. The channels were keyed from a remote control box. The box consisted simply of five switches, one for each channel, which were actuated by a single control stick. The horizontal tail and emergency parachute were controlled by the 3-channel receiver. Two of the channels of the 3-channel receiver were used to control the horizontal tail and the third channel was used to operate the emergency recovery parachute at the command of one of the pilots.

Control Mechanisms

The ailerons, rudder, and all-movable horizontal tail were moved individually by three 12-volt d-c electric-motor-powered actuators deriving their power from batteries. The aileron and rudder controls were moved from their neutral positions through preset angular deflections, which were $\pm 15^\circ$ for the ailerons and $\pm 6^\circ$ for the rudder, in response to control signals. (See fig. 3.) The rate of angular deflection for the ailerons was approximately 100° per second and for the rudder approximately 300° per second. The ailerons and rudder automatically returned to neutral when the control signals were stopped or when the parachute signal was given. This type of control action is referred to as flicker control. For one of the test flights the rate at which the horizontal tail was deflected upward was 10° per second and also had a 5° flicker movement superimposed on the regular horizontal-tail motion. (See fig. 3.) The rate at which the horizontal tail was moved up for the remainder of the test flights was 5° per second and without a flicker movement. (See fig. 3.)

Parachutes

As mentioned previously, two parachutes were installed on the model in order to recover it at the termination of the flight. A 12-foot-diameter flat-type parachute which is referred to as the main parachute was installed in a bag just in front of the vertical tail beneath a hatch; a 6.33-foot-diameter ring-slot-type parachute which was used in an emergency if the main parachute did not deploy was placed in a metal can and attached to the most rearward portion of the fuselage. Two electric motors were used to release the two parachutes, one motor for each parachute. These motors wound cables on drums to pull the release pins. Both motors were made electrically safe by breaking their ground connections with a time relay which was set to complete the grounds 3 seconds after the model was released into flight. This procedure insured that the parachutes would not be deployed inadvertently too closely below the helicopter with the possible hazard of entangling parts of the helicopter. In addition, both parachutes were made mechanically safe while the model was attached to the launching rig. The rear stabilizing arm of the launching rig held the main parachute cover in place and a straight pin attached to a short lanyard cord was used to hold the emergency parachute cover in place.

The main parachute and emergency parachute had drag coefficients of approximately 0.75 and 0.60, respectively, based on the laid-out-flat diameters including the diameter of the area of the cut-outs in the ring-slot-type parachute. Based on these drag coefficients and a model weight of 90 pounds, the rate of descent of the model was computed to be approximately 30 feet per second when the main parachute was used and 64 feet per second when the emergency parachute was used.

Instrumentation

An electrically driven 16-millimeter gunsight aiming point motion-picture type of camera, hereafter referred to as a GSAP camera, using a wide-angle lens (17-millimeter focal length) and color film was mounted in the airscoop of the model. It was positioned so as to photograph flow-direction vanes attached to a nose boom on the model and also to photograph control-position indicator lights which were mounted in the top section of the forward portion of the model fuselage. The flow-direction vanes were used to measure the angles of attack and sideslip of the model. The control-position-indicator lights for the rudder and ailerons were operated by switches mounted on the control-surface torque rods in such a manner as to turn the lights on when the controls were fully deflected. The lights for the horizontal tail were wired in parallel with the actuator motor and were turned on whenever the motor was running.

GROUND AND AIRBORNE EQUIPMENT

Tracking Equipment

Two tracking units consisting of modified power-driven gun trailer mounts (ref. 3) were used to permit photographing of the model with a camera equipped with telephoto lens and to assist the pilots in flying the model (fig. 4). The modifications consisted of adding a camera, two aluminum chairs, two 7-power binoculars, and one 7-power monocular to each gun mount. The two binoculars were used by a pilot and an observer and the monocular by the tracking operator to increase his accuracy in tracking the models. Before beginning operations the camera and sighting equipment on each tracking unit were alined by sighting on a target at a distance of about 1,500 feet which compared closely with the average distance between the tracking unit and the model. The longitudinal motion of the model was controlled by one pilot while the lateral motions were controlled by another pilot, a procedure successfully used by the Langley free-flight tunnel section in testing dynamic models. Each pilot was seated in a separate tracking unit. In order to observe and control the longitudinal motion of the model properly, one pilot was placed to one side of the model while the other pilot was placed to the rear of the model so that he could readily observe the lateral motion of the model. The pilots were about 1,000 feet apart. A diagram of the test area and the arrangement of the equipment is shown in figure 5.

Cameras

In addition to the camera in the model, four other 16-millimeter motion-picture cameras were utilized in recording data of the model flights to determine the motion and attitude. Several lenses of different focal lengths were evaluated during the test program to determine the proper size lens. One camera was equipped with a 24-inch telephoto lens and mounted on a tracking unit, whereas another camera was equipped with a 12-inch telephoto lens and mounted on a second tracking unit. The third camera on the ground was equipped with a 6-inch telephoto lens, was mounted on a tripod, and was operated manually. The fourth camera was equipped with a 4-inch telephoto lens and was used to track the model manually from the helicopter. The cameras equipped with the 24-inch and 12-inch telephoto lens were driven by electric motors and the cameras equipped with the 6-inch and 4-inch telephoto lens were driven by spring motors. In the present investigation it was assumed that each camera framing speed used was constant throughout each flight and that speed record was used as a time indicator.

Airborne Equipment

Helicopter.- A helicopter flown by a pilot of the Langley Flight Research Division was selected for the launching platform for the model because of its ability to fly slowly without danger of stalling. In order to determine the nature of the air flow beneath the fuselage of the helicopter at low and high speeds, a brief survey was made. The results of the survey indicated turbulent air-flow conditions at speeds below 50 knots; at higher airspeeds the air flow became fairly smooth and only a slight angularity existed. Based on the desire of having fairly smooth air flow for launching the model, it was necessary that the model be launched at a velocity of 50 knots or higher. For reasons of safety, however, the launching speed of the model was chosen so that, even if the model inadvertently pitched up to its maximum lift condition, it would not have sufficient speed to gain altitude and strike the helicopter. The stalling speed of the model was computed to be approximately 67 knots and the maximum safe launching speed was considered to be 60 knots. Based on the condition of air flow, it was decided to launch the model at 60 knots to obtain as much forward velocity as possible to keep the altitude loss before spin entry to a minimum and thus allow maximum altitude for determination of the spin and recovery characteristics of the model.

Launching rig.- The launching rig for the model (fig. 6) was attached to the lower end of a 5-foot-long vertical shaft which could be retracted or extended down from the helicopter. The model was lowered approximately 5 feet below the helicopter fuselage at the time of launch in order that the model would be out of the downwash effects of the helicopter rotor blades and the turbulent air flow around the helicopter fuselage, as mentioned previously. The launching rig consisted of four stabilizing arms and a single support hook. Two arms were used to position the model for the proper angle of attack at the time of launch and the other two arms prevented the model from rolling while on the rig. In order to provide sufficient ground clearance for the model, it was attached to the launching rig on the helicopter in the retracted position with the nose of the model facing rearward so that the vertical tail of the model projected into an open hatch in the floor of the helicopter. The control surfaces and the attitude of the model were positioned to produce approximately zero forces and moments.

Communications Equipment

The personnel of the two tracking units and the helicopter were in voice communication with each other at all times through a ground communications system and a ground-to-air radio. Although personnel in the tracking units were able to hear the voice transmissions from the helicopter, the personnel in the helicopter could not hear voice transmissions from the tracking units directly. Therefore one person was used to relay messages from the tracking units to the helicopter and also to direct the operations. His duties were to see that all positions were ready for the drop, to see that the helicopter was in the correct position for the drop, and to give the countdown for the drop.

METHODS FOR OBTAINING DATA

The angles of attack and sideslip of the model were obtained by use of three flow-direction vanes photographed on the end of a nose boom. These three vanes, which were used to measure the components of the linear velocities, had one axis of rotation each and are referred to as roll, yaw, and pitch vanes. (See fig. 7.) The roll vane was a single vane since it rotated in a plane perpendicular to the line of sight of the camera and thus its position could be read easily by a protractor. Since the yaw and pitch vanes rotated in planes which were parallel to the line of sight of the camera, the angular displacement could not be read easily. Therefore, twin vanes were used to facilitate the accurate measurement of these angles. The positions of these two vanes were determined by measuring on the film the projected distance between the edges of the vanes and the axis of rotation and also by measuring the projected distance between the ends of the vanes. These distances were then converted to angular deflections by using a calibration curve which had linear displacements plotted against angular deflections. The techniques used for reducing these vane angles of attack and sideslip at the end of the nose boom are essentially the same as those described in reference 2.

Since the angular velocities and resultant linear velocity of the model were not measured in this investigation, the angles of attack and sideslip at the center of gravity of the model could not be determined accurately. However, since the length of the boom on the model $\left(13\frac{1}{2}\text{ feet, full-scale}\right)$ was comparable to normal boom lengths on airplanes, the angles of attack and sideslip data reported herein should, in general, be comparable to full-scale data which are usually presented in reference to the nose-boom location.

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As previously mentioned, a series of lights, which were also photographed by the GSAP camera, were used to indicate when the rudder and ailerons were fully deflected and when the horizontal tail was being deflected.

TESTING TECHNIQUE

The helicopter with the model attached to the launching rig took off and climbed to a predetermined altitude for the launching of the model. The altitude selected was a compromise since it was desired to launch the model at an altitude as high as possible in order to have a relatively long flight time and yet it also was desired to launch the model at a low enough altitude in order to observe it as easily as possible. Based on preliminary tests at several altitudes, it was ascertained that an altitude of 2,500 feet would be satisfactory for the testing of this model. At the desired altitude, the helicopter circled the field preparatory to dropping a bag of sawdust to determine approximately the wind drift and also to allow the trackers on the ground an apportunity to practice by tracking the bag. Just before the bag was dropped a countdown was made. The countdown was used to alert the pilots and trackers so that they would be ready for the drop. Next the model was lowered and rotated 180° so that the nose pointed forward. A final radio control checkout was made on the model as the helicopter again circled the field. On the final approach to the field a countdown was made and the model was launched. Shortly after the model was launched, a spin was attempted by various control movements, after which recovery from the spin generally was attempted. When the model had descended to an altitude of approximately 500 feet as judged by personnel on the ground, the parachute was released. A sketch showing the model being launched and entering a spin is presented in figure 8.

TEST CONDITIONS

The model used was ballasted to simulate dynamically a typical fighter airplane at an altitude of 31,000 feet (ρ = 0.000857 slug/cu ft)

For this condition, the total flying weight of the model was approximately 90 pounds and the wing loading was 18.9 pounds per square foot. The center of gravity was located at 32.4 percent of the mean aerodynamic chord. The dimensional characteristics for this configuration are presented in table I and the mass parameters and control deflections in table II. Several flights were made and four typical flights are presented. The crossflow Reynolds number based on the average depth of the fuselage forebody ranged from about 420,000 to 505,000 based on the computed lowest and highest rates of descent encountered in the tests; these rates of descent were 94 and 113 feet per second, respectively. For these same rates of descent the Reynolds number based on the mean aerodynamic chord of the model ranged from about 790,000 to 960,000, respectively.

PRECISION

The results obtained from tests of the radio-controlled model are believed to be accurate within the following limits:

α, deg	±2
β, deg	±4
Ω, rps	±0.05
Turns before recovery attempted	±1/8
Turns for recovery	±1/8

The accuracy of measuring the weight and mass distribution of this model is believed to be within the following limits:

Weight, percent	±1
Center-of-gravity location, percent $\bar{c}$	±1
Moments of inertia, percent	±5
Controls deflection, deg	±5

Because it is extremely difficult to ballast models exactly and because of inadvertent damage to models during tests, the measured weight and mass distribution of this model varied from desired values within the following limits:

Weight, percent	0 to 3 high
Center-of-gravity location, percent $\bar{c}$	1 forward to 1 rearward
Moments of inertia:	
I_X, percent	0 to 4 low
I_Y, percent	0 to 13 high
I_Z, percent	0 to 15 high

For some flight conditions, high control-surface hinge moments were encountered as compared with the hinge moments encountered during most of the flights. Therefore, there were portions of the flights during which the ailerons and rudder were forced back some amount from their fully deflected positions. For these portions of the flights, the exact aileron and rudder deflections were not known and had to be estimated from observations of the film records obtained from the cameras. These data are presented on the graphs by a dashed line which indicates approximate deflections rather than by the solid lines which indicate exact deflections.

The time histories of the flights include motions such as stalls, post-stall gyrations, incipient and developed spins, and spin recoveries; these motions are identified and described on the figures. In some instances, certain portions of the time histories are shaded to indicate that the transition of one motion to another is impossible to discern exactly. The time histories are presented in terms of full-scale values and thus the real time scale has been multiplied by a scale factor of three to obtain a simulated full-scale time. It should be noted that partial stalling of the wing of the model is considered to begin at an angle of attack of approximately 16° and complete stalling of the wing occurs at an angle of attack of about 32° as indicated on the time histories. This information is based on unpublished static-force data on a model similar to the one used in the present investigation.

RESULTS AND DISCUSSION

The results of the model flight tests are presented in the form of full-scale time histories in figures 9 to 12 and are summarized in table III. All flight tests were conducted with the center of gravity at 32.4 percent $\bar{c}$ because spin-tunnel tests on a scale model of a similar design had indicated that there would be a greater tendency to spin at this rearward location of the center of gravity than at normal locations. The time histories present the variations of the angles of attack and sideslip, deflections of the horizontal tail, ailerons, and rudder, and the number of turns in a spin. The four flights presented are considered to be satisfactory and to be typical of results obtainable with the present technique and instrumentation. Two of the flights were continued into developed spins and the other two were primarily incipient spins. Spin recovery was attempted for all except the first flight. Space attitude angles were not measured with the present technique, but approximate attitudes and ensuing motions of the model are described as seen from films of the flights. The test results are of a preliminary nature and were intended primarily for orientation purposes and familiarization with the technique.

It should be noted that, based on spin-tunnel experience and as explained in reference 4, it could be anticipated that, for the test vehicle used, which had its mass distributed heavily along the fuselage, the rudder and horizontal tail would be relatively unimportant for the termination of the spin rotation and that the ailerons would be the primary control. Therefore, for all spin-recovery attempts in the present investigation the ailerons were moved with the spin. When a spin recovery is attempted, the number of turns for recovery are measured from the time the control surfaces are moved until the spin rotation ceases. The recovery characteristics are considered to be satisfactory if recovery from the spin occurs in $2\frac{1}{4}$ turns or less.

Model Flight Test Results

Flight 1.- For this flight (fig. 9), it was intended to obtain a developed spin entered from a wings-level pull-up maneuver. The horizontal tail, however, was inadvertently pulled up to 55° instead of its normal setting of 30°. At the beginning of the flight, the model pitched up violently and the stick, which was back, was released inadvertently ($t = 6.3$ seconds) and then quickly pulled back again. It is felt that, since the stick was released only briefly, it did not affect the incipient motion of the model. The rapid pitch-up of the model apparently was due to the quick flicker movement of the horizontal tail (5° up) plus the relatively high rate of horizontal-tail-up travel (10° per second). The model started turning to the left and oscillated about all three axes in an incipient phase of a spin. After about $1\frac{1}{4}$ turns ($t = 18$ seconds) the oscillations decreased, especially in pitch, and shortly thereafter, ailerons were moved against the spin (stick right in the left spin) to promote the spinning motion. At this time, the rudder was accidently deflected against the spin but was quickly corrected and deflected with the spin. The model continued to spin for two more turns (total of $3\frac{1}{4}$ turns) at which time the parachute was actuated to retrieve the model. The rate of rotation of the developed spin was unusually low (0.11 revolution per second, full-scale); spin-tunnel experience indicates that this condition was probably due to the abnormally large upward deflection of the horizontal tail. The angle of attack of the developed spin ranged between 50° and 90° and the average angle of attack was about 65°. Thus for this flight, the objective to enter a developed spin from a wings-level pull-up was achieved.

For this flight and all subsequent flights, when the main parachute was deployed, the model oscillated considerably while descending. The oscillation resulted primarily from the fact that there was a single attachment point between the model and the parachute and also a slightly unstable parachute was used.

Flight 2.- For this flight (fig. 10) it was intended to obtain a developed spin to the right from a roll to the right. From the ensuing spin, recovery was to be obtained by movement of ailerons with the spin (stick right in right spin). Immediately upon launching the model, back stick was applied; shortly thereafter in order to initiate a right roll, the stick and rudder were put full right briefly and then neutralized. It was subsequently learned that the model was dropped at too low an airspeed (only 45 knots) for this flight and, as indicated in figure 10 ($t = 2$ seconds), the stall was approached rapidly. Because of the deflected ailerons and rudder and because the model was below the stall, the model rolled right quickly about 90° and then rolled back when the ailerons were neutralized as the model pitched beyond the stall. As indicated in figure 10, the model did not turn and thus did not enter a spin as expected; instead, a post-stall gyration persisted ($t = 5$ to 24 seconds). Another spin attempt was made after the stall had occurred by moving the stick full left ($t = 13.2$ seconds). Although it was intended to cross the controls when the model entered the spin, the ailerons and rudder for this flight inadvertently remained combined and, as a result, the rudder also moved to the left. It is felt that the rudder setting before and after the recovery attempt was of relatively little significance in influencing the results obtained inasmuch as spin-tunnel data indicate that at the high angles of attack involved, it was shielded and relatively ineffective. The model turned to the right and entered an incipient spin ($t = 24.5$ seconds). The motion of the model was more oscillatory than for flight 1 and a fast, relatively steady, flat right spin developed. This developed spin differed from that of flight 1 in that its rate of rotation was much faster (approximately 0.3 revolution per second, full-scale); the angle of attack ranged from 65° to 80°. After a total of $5\frac{1}{4}$ turns, a recovery was attempted ($t \approx 44$ seconds) by moving the ailerons to full with the spin. (Because of the combined controls, rudder also moved to with the spin.) The angle of attack and rate of rotation decreased somewhat, but the ailerons apparently were inadequate to effect a satisfactory spin recovery $\left(2\frac{1}{4}\text{ turns or less}\right)$ for this spin condition. After about $2\frac{1}{2}$ additional turns, the parachute was deployed. Thus, although a developed spin to the right was not achieved by rolling the unstalled model to the right, a developed spin to the right was obtained when the stick was moved left after the model had stalled. A satisfactory recovery could not be obtained from this spin.

Flight 3.- For this flight (fig. 11), it was intended to more or less duplicate flight 1 (wings-level pull-up) except recovery was to be attempted with ailerons alone from the incipient phase of the spin. With the ailerons neutral, the model entered a gentle stall ($t = 4$ seconds) and shortly thereafter began to oscillate in yaw slightly to the left and right in a post-stall gyration which extended from $t = 6$ to 16 seconds.

During this period, the stick was moved to the right (t = 11 seconds) as the model was yawing to the left in an effort to induce a spin to the left. Shortly thereafter, the model yawed slightly to the right and then back to the left as it entered an incipient-spin condition for approximately three-quarters of a turn (t = 16 to 22.5 seconds). Then the stick was moved full left (ailerons with, t = 23 seconds) and a recovery was obtained in about 1/2 turn (that is, the spin rotation ceased, t = 30.6 seconds). Because the horizontal tail was full up, however, the model remained at an angle of attack above the stall and, since the stick was still left, the model began yawing right because of the adverse yaw of the ailerons. The ailerons were now neutralized but the model continued to turn for $1\frac{1}{2}$ turns. The motion was somewhat oscillatory and appeared to be a developed spin. Ailerons were then moved full with the spin (stick right, t = 38.8 seconds) and the angle of attack decreased appreciably (t = 40 to 46.5 seconds) and the rotation slowed somewhat; however, the spinning motion could not be terminated in $1\frac{1}{2}$ turns. At this time the parachute had to be ejected because of proximity to the ground and the ailerons were neutralized. The model spun an additional $1\frac{1}{2}$ turns before the parachute terminated the flight. Thus for this flight the objective to enter and recover from an incipient spin was accomplished satisfactorily; in addition, a developed spin was encountered from which a recovery could not be obtained in $1\frac{1}{2}$ turns.

Flight 4.- For this flight (fig. 12) it was intended to more or less duplicate flight 2 (roll to right) except recovery was to be attempted by ailerons alone from the incipient phase of the spin. As the horizontal tail moved up and the model approached the stall, right stick was given and the model rolled right. It appeared that the model had rolled right too far; therefore, the pilot corrected with left stick briefly (t = 7.8 seconds) just as the model went beyond the stall and entered a post-stall gyration. Shortly thereafter (t = 11.4 seconds) the model started turning to the left as it entered what appeared to be an incipient phase of a spin. Right stick (ailerons against) was given briefly to help promote the spin and then a recovery was attempted from the incipient spin by moving the stick full left (ailerons with); the model, which had been turning for about 1/4 turn to the left (from t = 11.5 to 14.2 seconds), recovered from the incipient spin in an additional 3/4 turn and then started turning to the right because of the adverse yaw of the deflected ailerons. The stick was kept left as the model made 2 turns to the right. Although the motion was very oscillatory, the model appeared to have entered a developed spin. Ailerons were moved full with this spin (stick right) and a recovery was effected in $1\frac{3}{4}$ turns (t = 33.0 to 44.6 seconds); the angle of attack remained above the stall because of the up-horizontal-tail setting.

The model then started turning to the left just as the parachute was deployed. A summation of this flight indicates that the model entered an incipient spin to the left and recovered satisfactorily; in addition, a developed spin to the right was obtained from which a satisfactory recovery also was obtained.

Comparison With Wind-Tunnel and Full-Scale Results

An analysis has been made of the current-model flight-test results based on comparisons with results for a similar design from several wind tunnels and from full-scale tests. Because, as indicated in reference 2, the fuselage nose may have an appreciable effect on spin and recovery characteristics, and the effect may be critically dependent on cross-flow Reynolds number, static tests had been made in the Langley 300 MPH 7- by 10-foot wind tunnel on a model similar to the one used for the current flight tests. These results indicated that, at high angles of attack (approximately 70° to 90°), a propelling moment (pro-spin yawing moment) was obtained at the nose of the model at a Reynolds number of 300,000 (based on average depth of fuselage forebody). At a Reynolds number of 400,000 or greater, however, the propelling moment disappeared and a small damping moment (anti-spin yawing moment) replaced it. Results (unpublished) subsequently obtained from a similar model mounted on a one-degree-of-freedom yawing balance in a low-speed tunnel were in agreement with the aforementioned results; for the angle of attack tested (90°), the nose of the model developed a propelling moment at a Reynolds number of about 340,000 based on the average depth of the fuselage forebody. It is felt that the propelling moment would probably exist down to approximately an angle of attack of 70°. For a Reynolds number of about 415,000 and greater, the propelling moment disappeared and was replaced by a damping moment. Therefore, based on the results of these investigations, the critical value of the Reynolds number, that is, the point where the moment on the nose of the model changes from a propelling moment to a damping one appears to be between 340,000 and 400,000 for this design. Thus, inasmuch as the Reynolds number for the radio-controlled model tests ranged from 420,000 to 505,000, the present-test results should be comparable to full-scale results.

Results (unpublished) of spin tests on a similar small dynamic model tested in the Langley 20-foot free-spinning tunnel at a Reynolds number of about 90,000 indicated that the model was capable of two types of spins. One was a very fast, extremely flat, fairly steady spin at an angle of attack of approximately 87° from which recoveries were unsatisfactory or unobtainable. The other spin was steeper, more oscillatory, and had a lower rate of rotation; recoveries from this type of spin ranged from satisfactory to marginal or unsatisfactory. The spin-tunnel model results indicated a modification or control device was necessary to ensure satisfactory recoveries even from the steeper, slower turning spin. Full-scale data indicated that a similar airplane had a moderately steep somewhat oscillatory spin from which recoveries ranged from marginal to unsatisfactory when a control device was not used. These full-scale results are in qualitative agreement with the spin-tunnel results with the exception that the fast flat spin on the model was not encountered on the airplane. Thus it appears that the flat spin obtained on the spin-tunnel model probably resulted from a propelling moment on the nose associated with the low Reynolds number at which the spin-tunnel model was tested.

Although the data obtained from the model flight tests were meager, the spin and recovery characteristics of the radio-controlled model appeared to be in qualitative agreement with full-scale data. As was the case for a similar airplane, the model results showed a possible range in recovery characteristics from developed spins that varied from satisfactory to unsatisfactory. Satisfactory recoveries were obtained on the model, however, from the incipient spins, which were up to three-quarters of a turn. These results are in general agreement with full-scale results and indicated that a similar airplane would recover from the incipient phase of the spin in 2 turns or less.

It appears essential in order to avoid a spin in the opposite direction that the horizontal tail be moved to neutral or down when the spin rotation ceases and thus unstall the model. Also, the rudder and especially the ailerons should be neutralized to eliminate a yawing tendency at angles of attack above the stall. Although at angles of attack below the stall the model tended to roll with the ailerons (right roll when stick right), at high angles (above the stall), the yawing moment due to the ailerons appeared to be the significant factor in initiating rotation in a given direction (yaw left when stick right).

Evaluation of Technique

In general, the technique of launching radio-controlled models from a helicopter to study the incipient- and developed-spin characteristics of airplanes appears to be feasible and the results are generally satisfactory. The longitudinal- and lateral-control pilots could observe the model flights fairly well, although in some instances they had difficulty in determining the direction of rotation of the model in a spin entry. However, with more experience it is expected this difficulty will be overcome. If it should become necessary to launch the model from a higher altitude than the present tests, it may be desirable to either control the model from the helicopter from which it was launched, or from a second helicopter, and/or obtain better optical equipment for visual tracking from the ground. The present type of control system was used in the investigation since it was a proven type and readily available. Although the present control system using a flicker control for the ailerons and rudder was adequate for these tests the system was limited with regard to maneuvering the model precisely. Moving the horizontal tail at a fixed rate was inadequate since it is desirable to be able to control the movement of the horizontal tail in order to vary the speed at which the stall is approached. In addition, it is necessary to move the horizontal tail down immediately after cessation of spin rotation to unstall the model and prevent it from entering another spin. Thus there is a definite need for a proportional-control radio system which will permit rapid and accurate positioning of the control surfaces. Adequate proportional-control equipment is not available at the present time.

The tracking units performed well in that the operators followed the flight of the model smoothly without ever losing sight of it. In some instances, the tracking unit vibrated slightly and thus caused a blurring of the film records taken by the camera with the 24-inch telephoto lens; however, the motion of the model still could be followed easily. The camera equipped with the 12-inch telephoto lens was in most cases barely adequate in that the model images were somewhat small, and the camera having a 6-inch telephoto lens was completely inadequate because of the small image size. Therefore, based on the foregoing discussion a 24-inch telephoto lens appears to be the optimum size that should be used to track the model from the ground with the present equipment. The pictures obained from the helicopter with the camera with 4-inch lens appeared to be adequate since this camera was much closer to the model so that the image size was sufficiently large. It was felt that use of a synchronized timing signal or at least a time signal superimposed on all film records would be desirable in order to increase the accuracy of the time scale.

The angles of attack and sideslip of the model at the nose could be determined fairly accurately from the motion-picture records by the use of the flow-direction vanes on the nose boom of the model. Although the lights in the model which indicated whether the controls were fully deflected operated satisfactorily most of the time, when the controls did not deflect fully because of large hinge moments, the position of the controls had to be estimated. It was indicated that a fairly stable quick-opening parachute having a stable attachment point to the model is desirable for these types of tests since, if the parachute or model oscillates too much, it may damage the model when it strikes the ground and a quick opening parachute allows more altitude for the tests.

The launching rig operated satisfactorily in that the model dropped away smoothly upon release. Although ground clearance for this model was not a problem when it was attached beneath the fuselage of the helicopter, if a larger model is used it may be desirable to attach the model at some other location on the helicopter or obtain a helicopter with greater ground clearance.

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CONCLUSIONS

The following conclusions are based on the results of an investigation to develop a technique utilizing a free-flying radio-controlled model to study the incipient- and developed-spin characteristics of a typical fighter airplane.

1. In general, the results obtained during the investigation were considered to be satisfactory and indicated that the technique was feasible for studying the incipient and developed spin characteristics of airplanes.

2. The model spin and recovery characteristics obtained by use of this technique are in general agreement with spin-tunnel and full-scale results.

3. The present radio-control equipment, although limited with regard to maneuvering the model precisely, has been fairly adequate for the development of the technique. However, in order to realize the full potential of this technique, it is considered extremely desirable to use proportional-control equipment when adequate equipment becomes available so that rapid and accurate positioning of the control surfaces will be possible.

4. The measurement of the angle of attack and sideslip at the nose boom of the model by use of flow-direction vanes and a motion-picture camera in the model was considered to be a satisfactory method.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., October 28, 1958.

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF AIRPLANE REPRESENTED BY MODEL

Wing:	
Airfoil section at root	NACA 65A006
Airfoil section at tip	NACA 65A005
Area (including fixed chord-extension), sq ft	385.33
Span, ft	35.67
Aspect ratio (area includes chord-extension)	3.30
Root chord (on fuselage reference line), ft	16.83
Tip chord (including chord-extension), ft	4.66
Tip chord (without chord-extension), ft	4.16
Mean aerodynamic chord, $\bar{c}$, ft	11.78
Leading edge of $\bar{c}$ rearward of leading edge of root chord, ft	26.60
Sweep of quarter chord, deg	42
Dihedral, deg	-5
Taper ratio (without chord-extension)	0.247
Incidence, deg	-1
Ailerons:	
Total area, sq ft	41.98
Span of one aileron, percent of b/2	40.38
Horizontal tail:	
Airfoil section at root	NACA 65A006
Airfoil section at tip	NACA 65A004
Area:	
Total, sq ft	93.47
Exposed, sq ft	57.59
Span:	
Total, ft	18.09
Movable panel, ft	6.84
Root chord (on fuselage reference line), ft	9.00
Tip chord, ft	1.33
Sweep of quarter chord, deg	45
Dihedral, deg	5.42
Aspect ratio (based on total tail area)	3.50
Taper ratio	0.148
Longitudinal distance from 32.4 percent $\bar{c}$ to quarter chord of tail, ft	12.78
Vertical distance from center of gravity, ft	0
Vertical tail:	
Airfoil section at root	NACA 65A006
Airfoil section at tip	NACA 65A004
Total area (including dorsal), sq ft	82.36
Span, ft	9.57
Root chord (on fuselage reference line), ft	13.10
Tip chord, ft	3.42
Sweep of quarter chord, deg	45
Aspect ratio	1.24
Taper ratio	0.26

TABLE II.- MASS PARAMETERS AND CONTROL DEFLECTIONS

OF AIRPLANE REPRESENTED BY MODEL

Mass parameters:	
Weight, lb	24,116
$x/\bar{c}$	0.324
$z/\bar{c}$	0.026
μ, at an altitude of 31,000 feet	63.04
I_X, slug-ft^2	11,202
I_Y, slug-ft^2	92,992
I_Z, slug-ft^2	103,138
$\frac{I_X - I_Y}{mb^2}$	-860×10^{-4}
$\frac{I_Y - I_Z}{mb^2}$	-107×10^{-4}
$\frac{I_Z - I_X}{mb^2}$	967×10^{-4}
Control settings:	
Horizontal tail:	
Trailing edge up, deg	30
Trailing edge down, deg	10
Ailerons, deg	±15
Rudder, deg	±6

TABLE III.- SUMMARY OF TEST CONDITIONS AND RESULTS

Flight number		1	2	3	4
Incipient spins					
Direction of spin entry		Left	Right	Left	Left
Control positions in incipient spin	Rudder	Neutral	Left	Neutral	Neutral
	Ailerons	Neutral	Left	Right	Right
	Horizontal tail	Up	Up	Up	Up
Control positions for recovery in incipient spins	Rudder	--	--	Neutral	Neutral
	Ailerons	--	--	Left	Left
	Horizontal tail	--	--	Up	Up
Number of turns		$1\frac{1}{4}$	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{4}$
Number of turns for recovery		--	--	$\frac{1}{2}$	$\frac{3}{4}$
Range of angles of attack		25° to 95°	-20° to 95°	20° to 85°	35° to 90°
Range of angles of sideslip		-24° to 18°	-38° to 44°	-40° to 36°	-44° to 40°
Developed spins					
Direction		Left	Right	Right	Right
Control positions	Rudder	Right	Left	Neutral	Neutral
	Ailerons	Right	Left	Neutral	Left
	Horizontal tail	Up	Up	Up	Up
Control positions for recovery	Rudder	--	Right	Neutral	Neutral
	Ailerons	--	Right	Right	Right
	Horizontal tail	--	Up	Up	Up
Number of turns		2	$3\frac{3}{4}$	$1\frac{1}{2}$	2
Number of turns for recovery		--	No recovery	No recovery	$1\frac{3}{4}$
Total number of turns in incipient and developed spin prior to attempted recovery		$3\frac{1}{4}$	$5\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$
Range of angles of attack		50° to 90°	65° to 80°	50° to 90°	60° to 90°
Range of angles of sideslip		-18° to 10°	-16° to 42°	-22° to 34°	-26° to 40°
Average rate of rotation, rev/sec		0.11	0.30	0.20	0.25

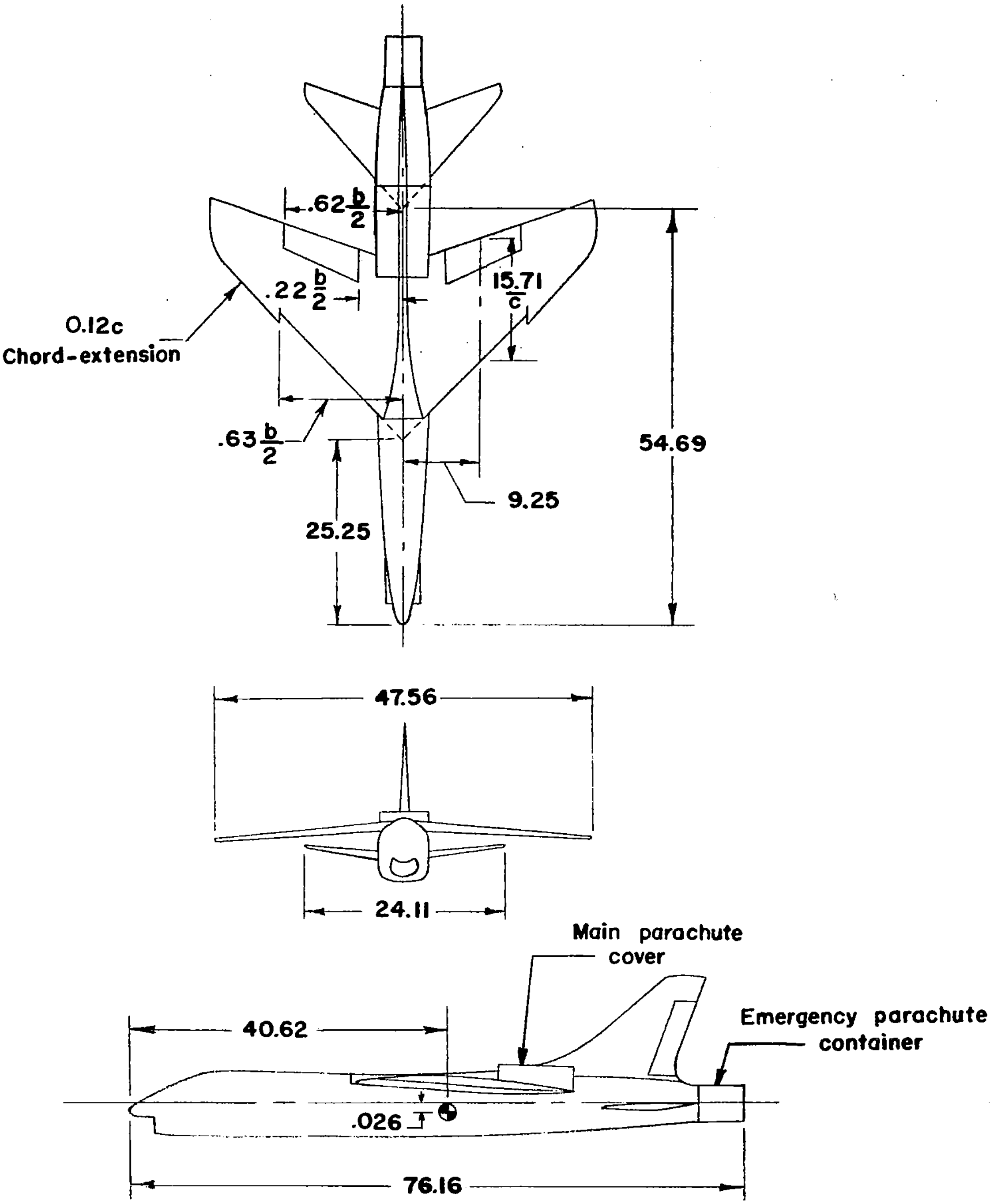


Figure 1.- Three-view drawing of the model used in the investigation.
All dimensions are in inches.

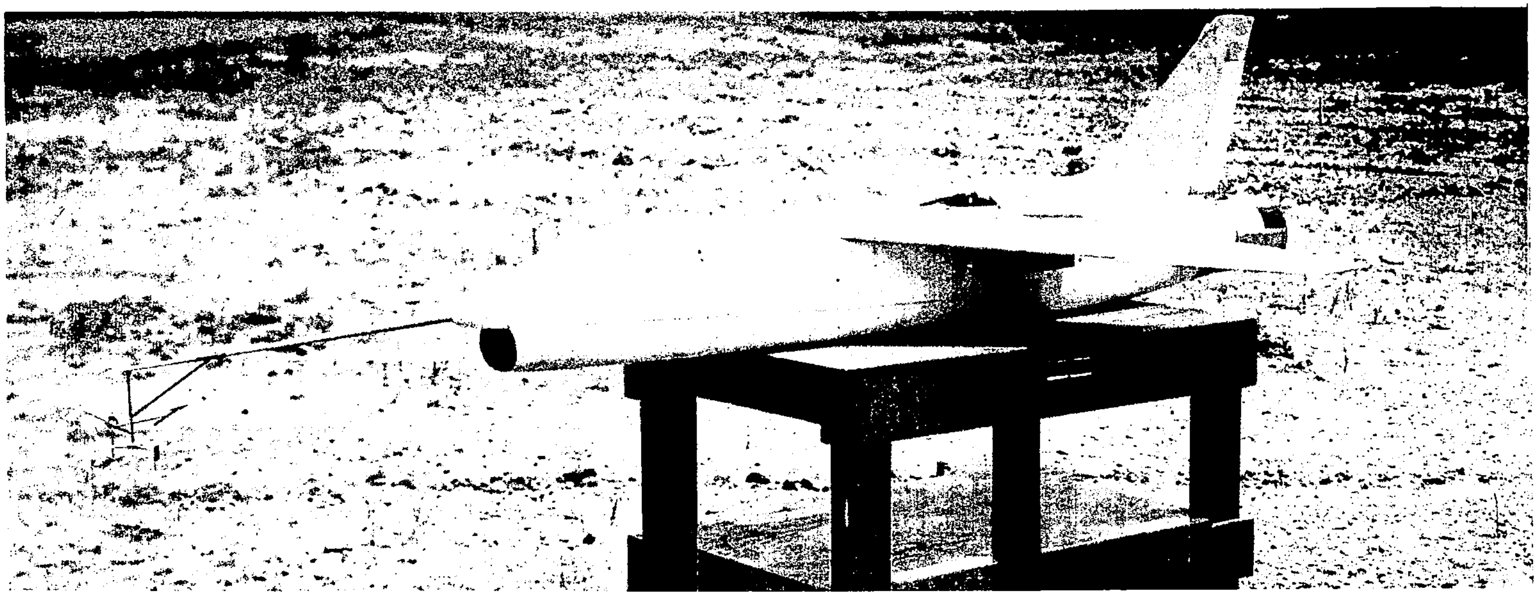


Figure 2.- The model used in the investigation. L-58-2727

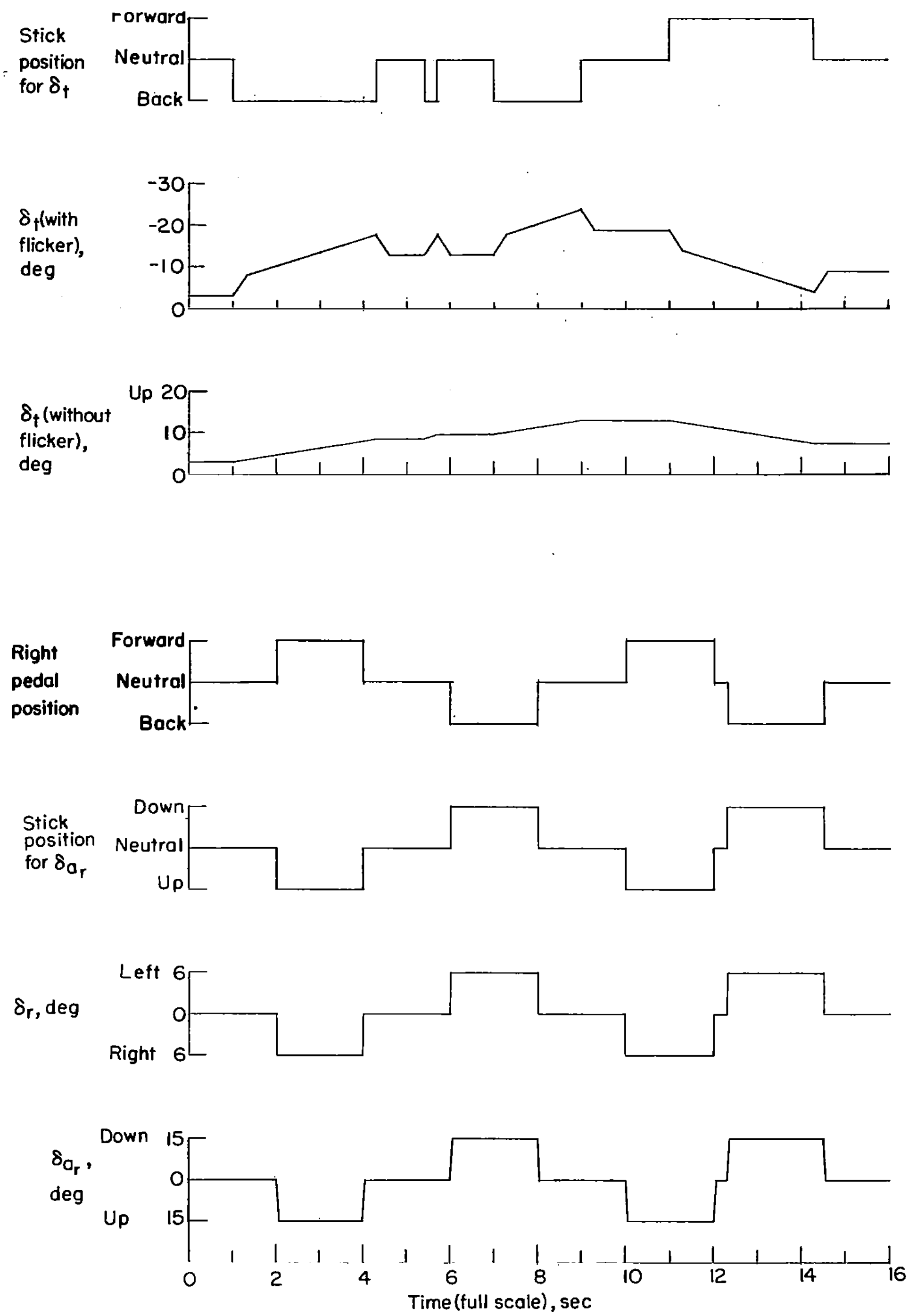
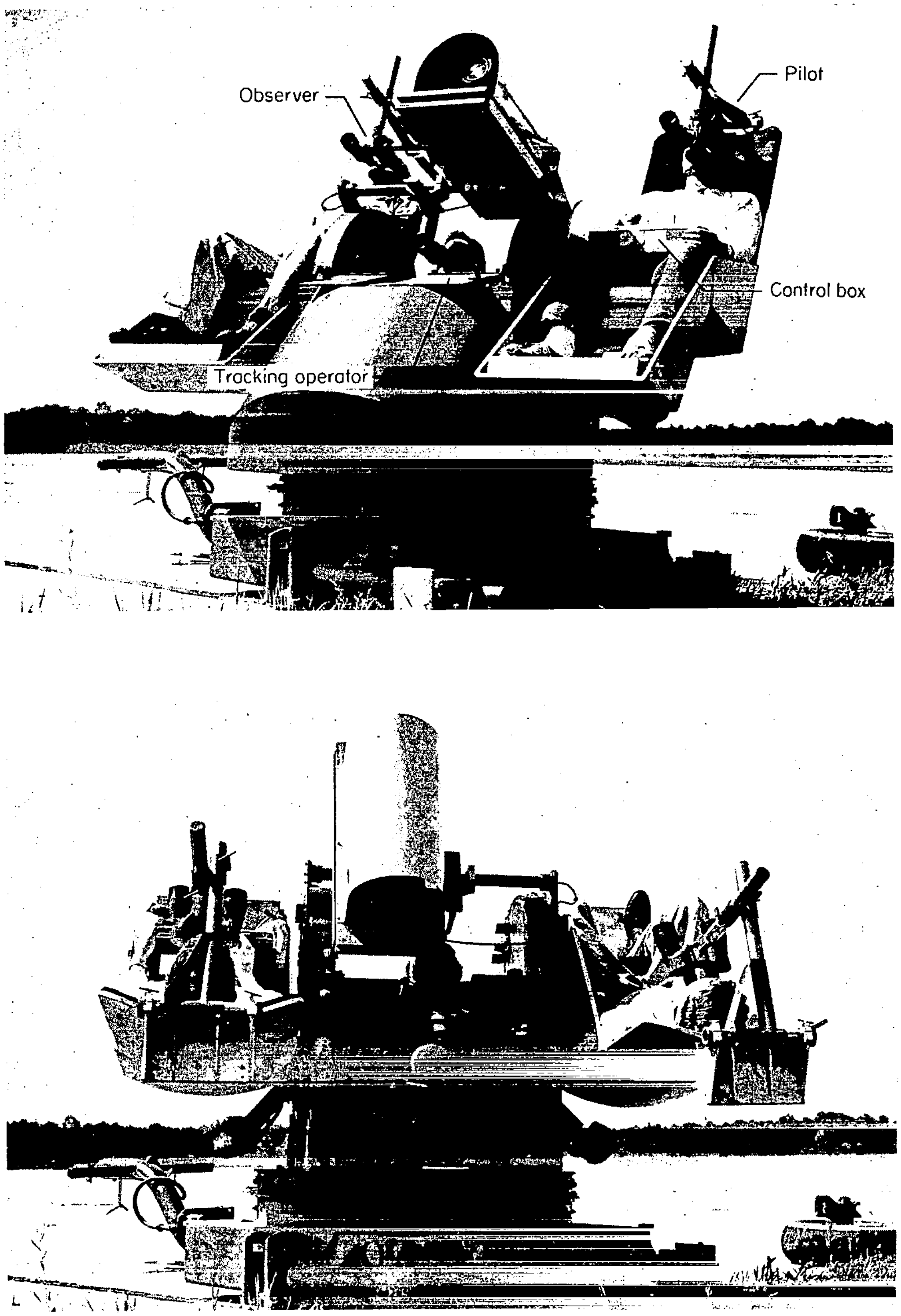


Figure 3.- Time histories showing typical variation of control surfaces with stick position.



L-58-133a

Figure 4.- One of two tracking units used in the investigation.

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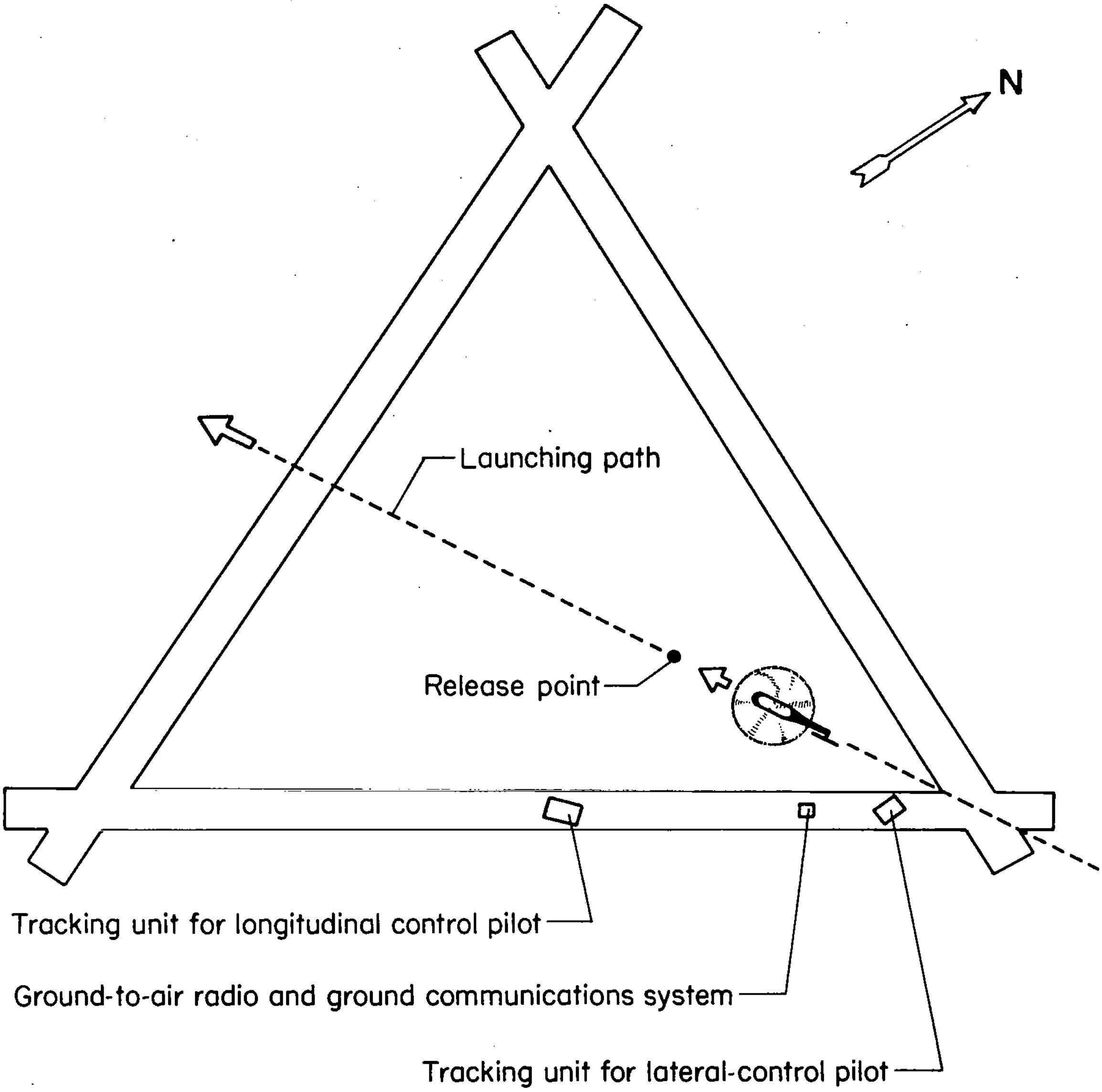
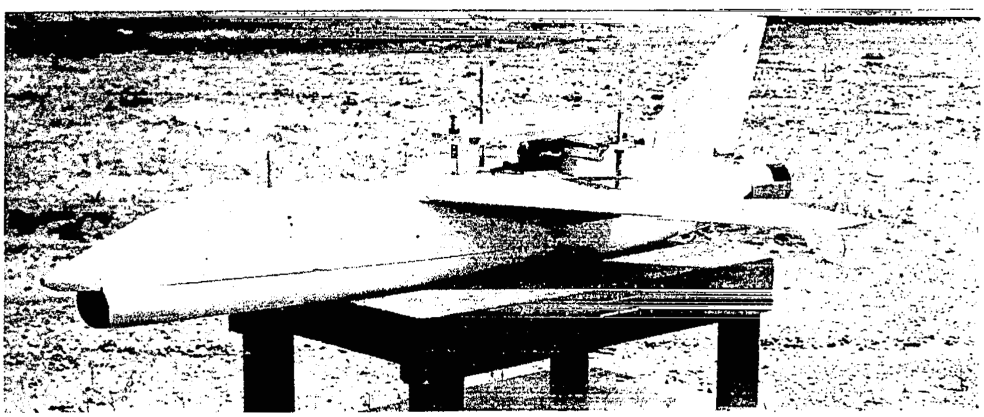


Figure 5.- Diagram of test area where spin investigation was conducted.

L-58-2723

(a) Model attached to helicopter in retracted position.



(b) Launching rig attached to model. L-58-2728

Figure 6.- Model launching arrangement.

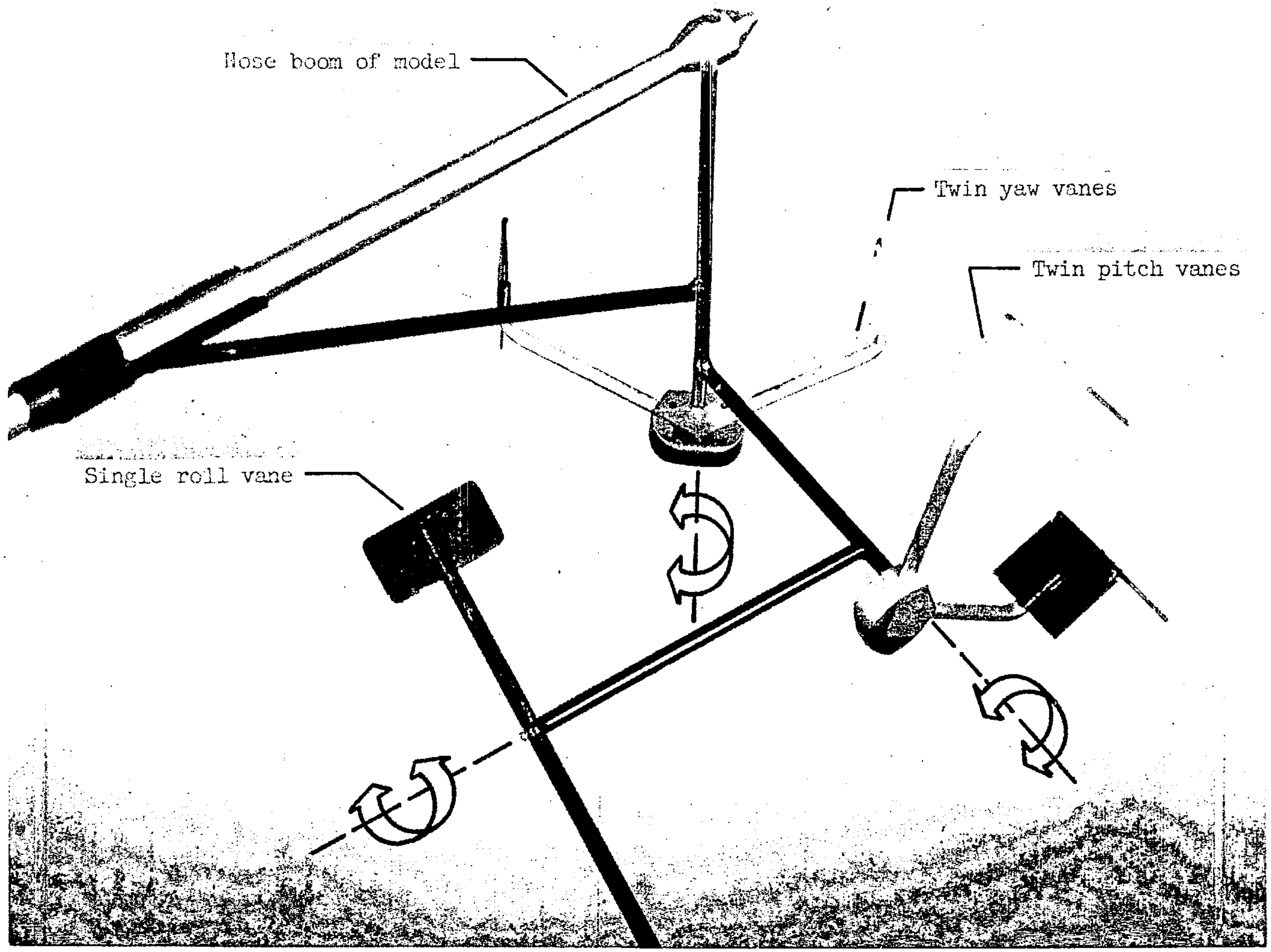


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Figure 7.- Photograph of three-vane nose-boom installation.

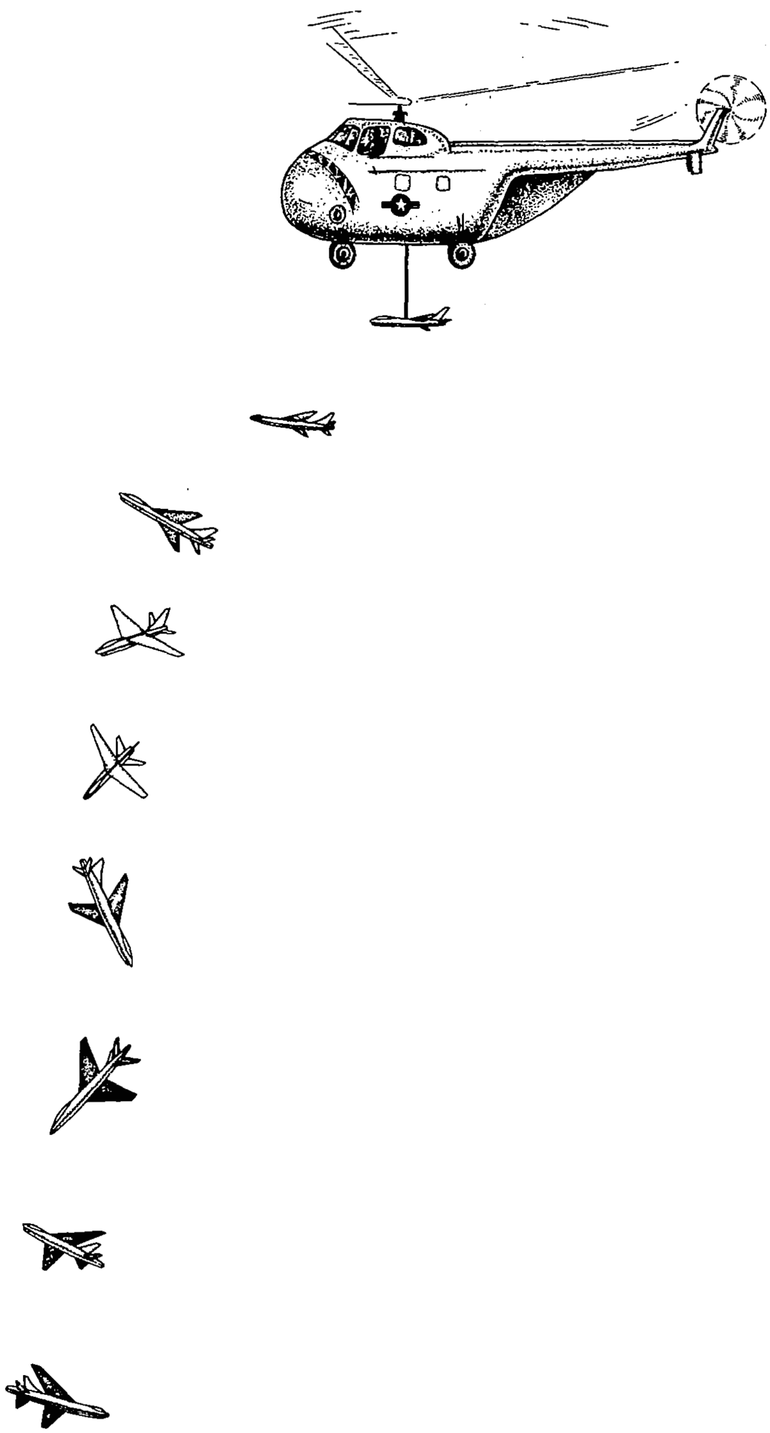

Figure 8.- Sketch of model being launched and entering a left spin.

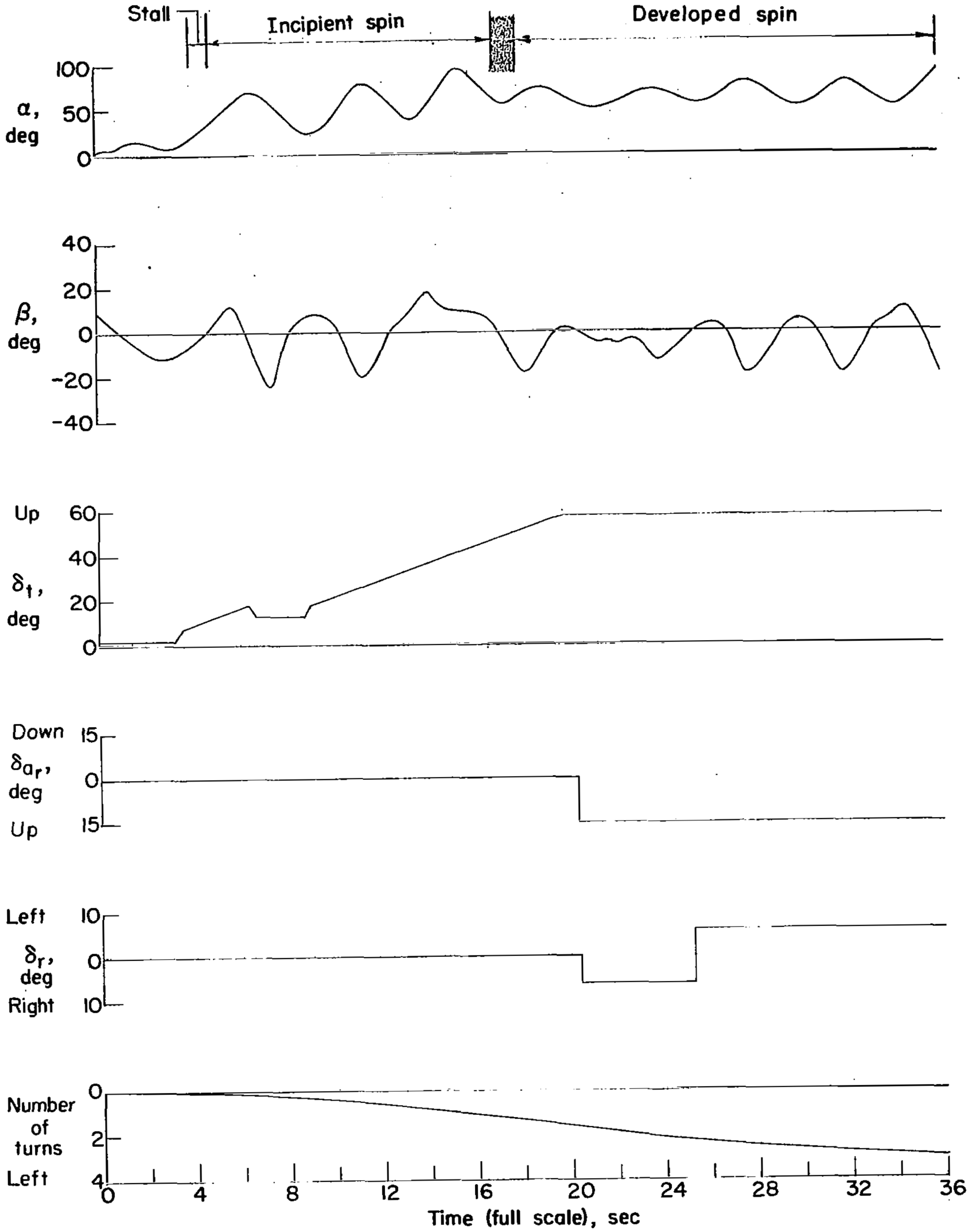

Figure 9.- Time histories of model flight tests. Flight 1.

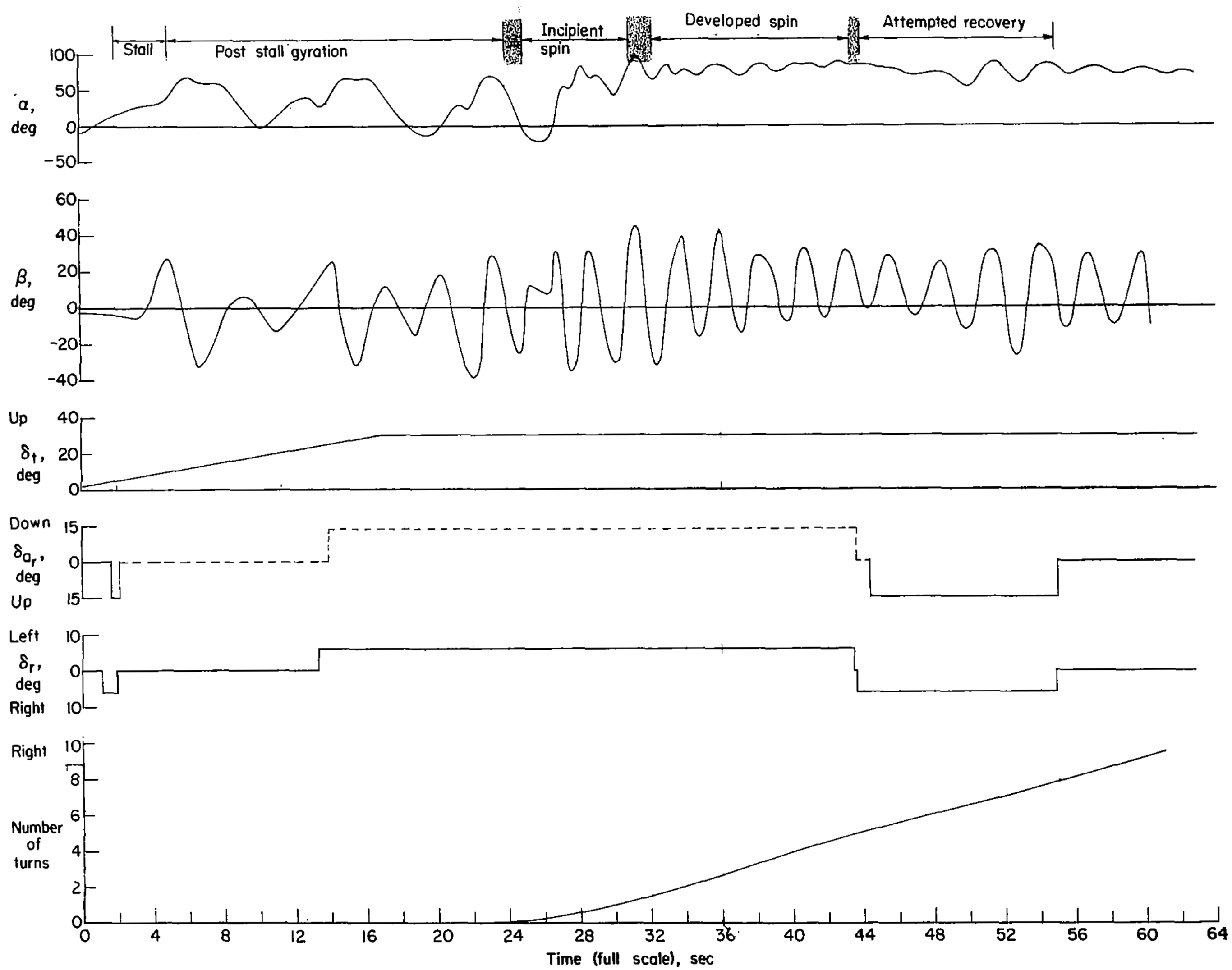

Figure 10.- Time histories of model flight tests. Flight 2.

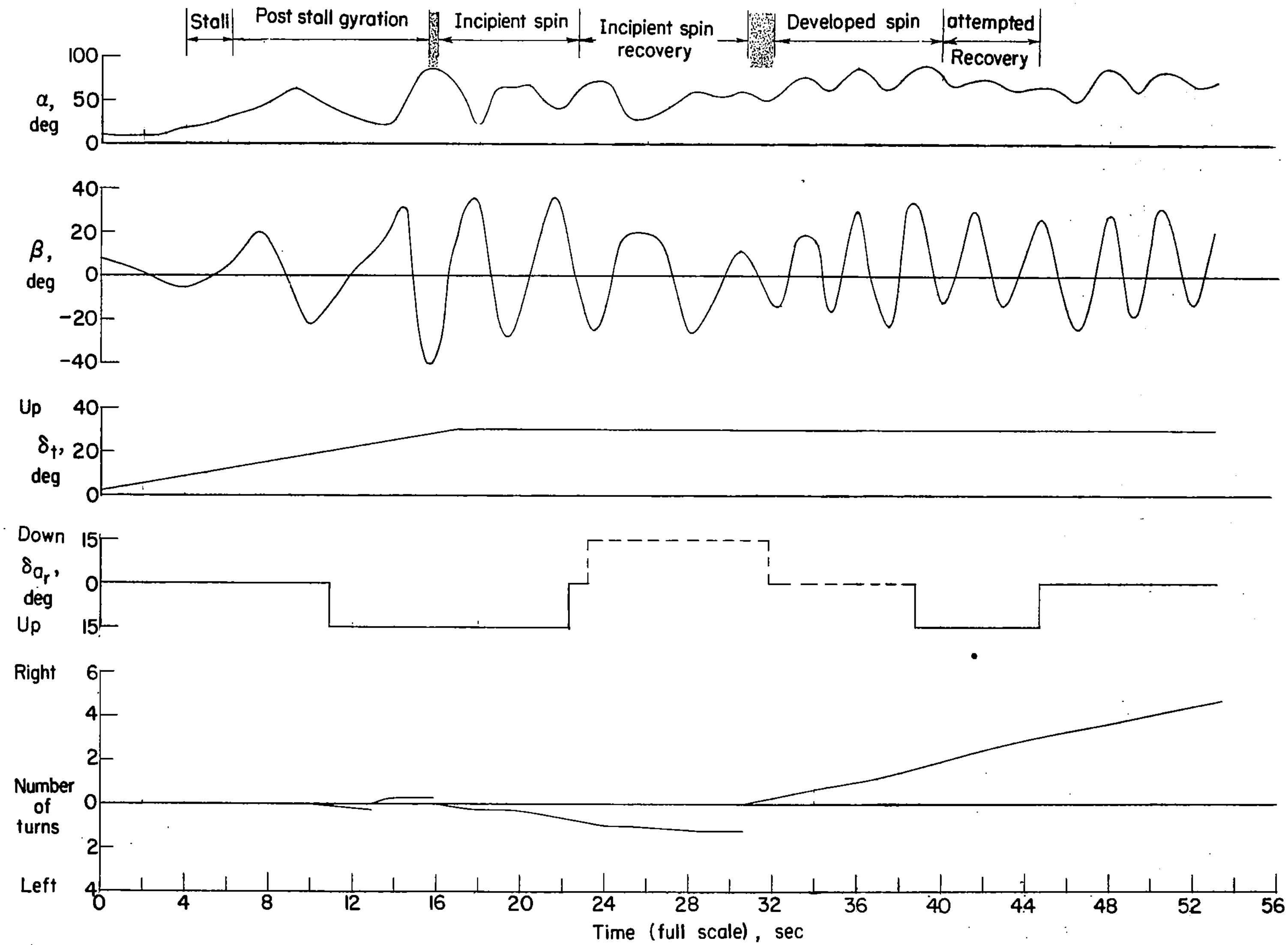

Figure 11.- Time histories of model flight tests. Flight 3. $\delta_r = 0^{\circ}$.

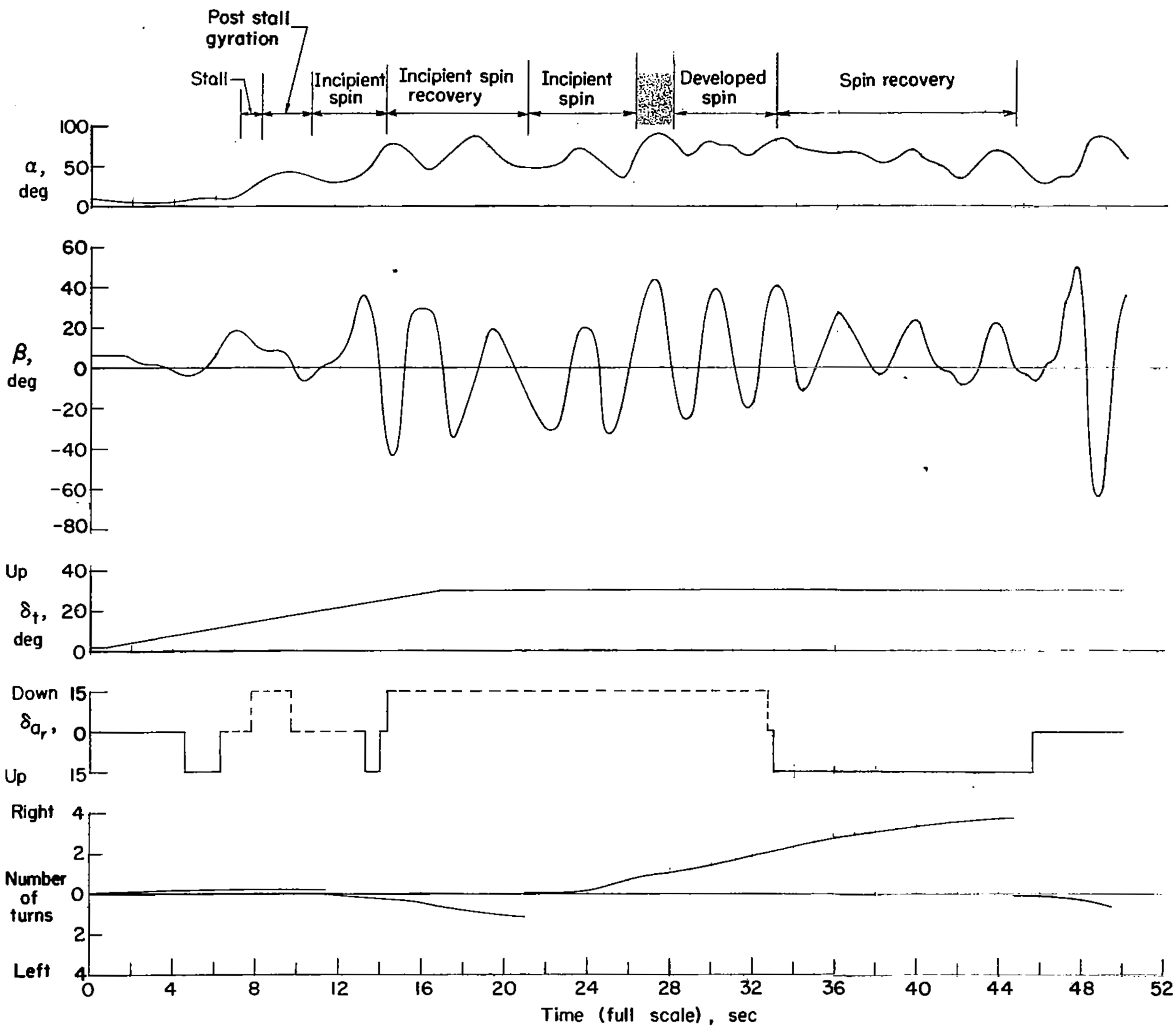

Figure 12.- Time histories of model flight tests. Flight 4. $\delta_r = 0^{\circ}$.

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